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A spike correction approach for variability analysis of heart rate sick infants

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HIGHLIGHTS

- Heart rate of sick infants contains abnormal spikes caused by artifacts.
- Presence of spike can affect heart rate variability analysis.
- We propose a method to correct the spikes in the heart rate of sick infants.
- An application to heart rate of premature infants is discussed.
- Spectral power differed between spike corrected and spike uncorrected data.

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ABSTRACT

In critical care monitoring, the heart rate (HR) offers valuable insight into the autonomic function of sick infants. However, the intensity of monitoring and clinical care such as intubation, suctioning, and venesection as well as routine movement, create a hostile environment for contamination of continuous signals. These artifacts usually present as spikes in the HR signal, which interfere with the characterization and subsequent evaluation of the HR. Post hoc spike removal is commonly required in research studies but is not feasible in clinical monitoring. We propose a two-step process to correct spikes in HR data. Step 1 comprises of two sub-steps to remove the spikes with upward deflection and downward deflection. In Step 2, we repeat Step 1, for different ϵ values and calculate root mean square (RMS) of the difference between the uncorrected HR and the corrected HR. The corrected HR that displayed either the smallest RMS value or the same RMS values for two or more ϵ values is considered optimally corrected data. We demonstrate the application of this approach to HR data collected from 5 preterm infants. We show that there is a significant difference between the spectral powers obtained for spike uncorrected and spike corrected HR.

1. Introduction

Cardiac beat-to-beat interval (RRi) calculated from an electrocardiogram (ECG) offers a convenient method of studying autonomic function at the bedside of critically ill infants [1]. Several signal processing techniques have been proposed to characterize the variability in RRi [2]. For example, the sympathetic and parasympathetic branches of the autonomic nervous

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system can be characterized by studying the slow and fast changes in the RRi, respectively [3–8]. Different techniques proposed for RRi characterization, irrespective of their operational principle, all aim at characterizing the slow and fast changes in the RRi. For instance, the standard deviation of normal-to-normal interval (SDNN) and the root mean square of successive differences (RMSSD) are used to study the sympathetic and parasympathetic components of the RRi, respectively. Similarly, power spectral analysis has been used to characterize RRi. Methods stemming from the concepts of nonlinear dynamics (Sample Entropy [1,9] and Approximate Entropy [10]) and statistical physics (detrended fluctuation analysis [DFA] [11] and phase-rectified signal averaging technique [12]) have also been used to study the RRi.

All of these methods used for RRi analysis assume that the tachogram is stationary. Modified approaches are being developed to characterize non-stationary RRi [13,14]. However, in some scenarios, the presence of spikes in the RRi adversely affects the characterization of RRi. An abnormal change in the heart rate (HR) caused by artifacts is what we call a spike in this work. One approach to the issue of non-stationarity in the HR signal has been to exclude those beats that occur outside of a physiologically plausible range [15]. The proposed approach in Ref. [15] defines the HR as a spike if the change in the HR from one beat to the immediate next beat is greater than the physiologically plausible range. Because the HR of infants can vary in a wide range (80–210 beats per minute [bpm]), it is difficult to set rigid bounds that define spikes in the neonatal HR using this technique [15]. Thus, a reliable real-time approach is needed to correct spikes in the infant tachogram during intensive care monitoring. To fill this void, we propose a two-step procedure to correct spikes in the HR. The first step involves an iterative procedure to correct spikes based on the ratio of the local maxima to their immediate minima, on both sides exceeding a predefined tolerance. The second step involves repeating Step 1 for different tolerance values. Finally, the threshold that yields optimal correction is identified using the root mean square (RMS) of the difference between the corrected HR and the uncorrected HR. The threshold for which RMS was a minimum or remained unchanged for two or more tolerance values is identified as an optimal threshold. We apply the proposed approach to 14 tachograms from 5 preterm infants and compare the power spectra of the uncorrected and corrected HR. The proposed application can be used in the real-time monitoring of HR variability.

2. Methods and materials

2.1. HR of preterm infants

We retrieved ECG from the analog port of the bedside monitor (Philips Intellivue MP70, Philips, MA, USA) using custom software developed in LabView 2010 Professional development systems (National Instruments Corporation, TX, USA). The ECG was sampled continuously at a rate of 1 kHz. The duration of the studies varied from 2 to 6 h. The ECG was bandpass filtered between 0.5 and 70 Hz and the R-wave was identified using a combination of Hilbert transform and adaptive threshold detection approach [16,17]. RRi was calculated as the time between two successive R-waves and HR (bpm) was calculated as a ratio of 60 to RRi expressed in seconds.

2.2. Spike correction procedure

Let the sequence x_i, $i = 1$ to N denote the HR (see Section 2.1 for details). To correct spikes we used the following two steps.

- Step 1 involved the following sub-steps:
  (a) We identified all the local maxima and minima in x_i. A local maximum was defined if a point $x_i > x_{i-1}$ and $x_i \geq x_{i+1}$. Similarly, a local minimum was defined if a point $x_i < x_{i-1}$ and $x_i \leq x_{i+1}$.
  (b) For each local maximum we defined r_i as the ratio of the local maximum to the average of immediate local minima on both sides of the maximum. If there was no local minimum on one of the sides of the maximum, we used the side for which the minimum was available and calculated r_i.
  (c) If $r_i > \epsilon$, we replaced this point with the median value of 10 beats starting 15 beats back in time from the current position; if 15 points were not available, we used the available number of points to calculate the median.
  (d) To correct spikes with downward deflection, we calculated $60/x_i$ (i.e. RRi). We then followed the sub-steps used to correct spikes with upward deflection. At the end of this step, we converted the sequence back to HR (i.e. we calculated the ratio of 60 to each point in the sequence).

  After correcting for the spikes with downward deflection, the baseline could change. Given a new baseline, some of the spikes with upward deflection that were not captured in the previous iteration might exceed the tolerance value and become a candidate for correction. Similarly, at the end of this correction, any change in the baseline might identify spikes with downward deflection as a possible candidate requiring correction. To check these aspects, we repeated the above sub-steps until the sequence entering a correction step remained the same at the end of the step, meaning, the sequence required no further correction. The termination of the correction process can happen either at the RRi or the HR. To ensure the algorithm outputs HR, we checked the magnitude of the output and if the values were less than one (indicating RRi) we calculated HR and used this for further analysis. In this work, we assumed the correctness of the data in the past and used them to correct the spike.